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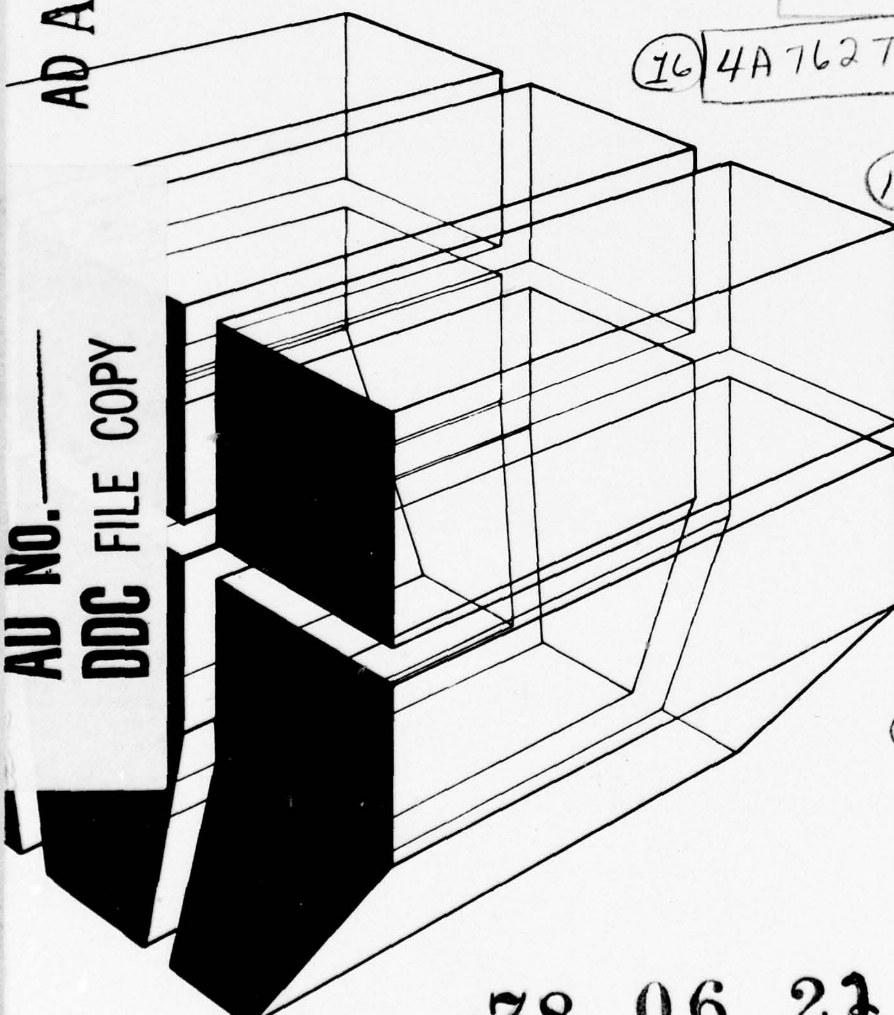

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Ernest M. Honig, Jr.
S. A. Hathaway

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This report is the first of a two-volume report that considers the prospects for applying coal technologies to military facilities. Current and emerging coal technologies are described and evaluated for possible current, near-term (1982), and long-term (1987) application to military facilities. Technologies considered are: conventional and advanced direct combustion of coal, coal gasification, and coal liquefaction. The impacts of applying the principal candidate processes of each of the three categories are discussed. (over)

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It has been concluded that there are no new advances in conventional direct combustion of coal and that current technology can be applied now and in the near-term. Fluidized-bed combustion may be a prospect for direct combustion by 1982. Current- to near-term coal gasification prospects are the Lurgi and Koppers-Totzek low-Btu processes and the Lurgi high-Btu process. A long-term coal gasification prospect is the CO_2-Acceptor high-Btu process. No coal liquefaction processes currently appear to be economically feasible for military-scale applications. Existing natural gas- and oil-fired boilers can be changed to fire low-Btu coal-derived gas by means of suitable burner modification; also, high-Btu gas can be directly substituted for natural gas.

Capital costs for direct coal combustion technologies (based on 5×10^{12} Btu/yr plant input capacity using bituminous coal) available for Army use are: stoker-firing, \$21.00/kBtu-hr (\$19.91/MJ-hr) and pulverized-firing, \$26.00/kBtu-hr (\$24.65/MJ-hr). Operating costs of available direct combustion technologies are: stoker-firing, \$5.25/MBtu-hr (\$4.98/GJ-hr) and pulverized firing, \$6.35/kBtu-hr (\$6.02/GJ-hr). No economic data for fluidized-bed combustion systems scaled for installation use are available. Capital costs under these same conditions are: Lurgi low-Btu, \$8.10/kBtu-hr (\$7.68/MJ-hr); Koppers-Totzek low-Btu, \$14.50/kBtu-hr (\$13.75/MJ-hr); and Lurgi high-Btu, \$16.40/kBtu-hr (\$15.55/MJ-hr). Operating costs for the Koppers-Totzek process are not available. All costs are given in current (FY77) dollars; the economics of using a given technology at a specific installation may vary greatly depending on site-specific factors.

The study recommends (1) that conversion of boilers to fire coal at Army installations use proven direct combustion processes until capital and operating cost estimates of near-term gasification systems are confirmed through demonstration and use; (2) that detailed technical/economic feasibility studies of using current and near-term coal-use technologies be conducted at at least four Army installations, and (3) that demonstrations of the Lurgi and Koppers-Totzek processes at nonindustrial Army installations be pursued with the Energy Research and Development Administration.

Volume II provides detailed technical and economic aspects of coal-use technologies.

FOREWORD

This research was performed for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Design, Construction, and Operation and Maintenance Technology for Military Facilities"; Task 06, "Energy Systems"; Work Unit 016, "Coal Utilization." The OCE Technical Monitor is Mr. L. Keller, DAEN-FEU-M.

Research contained in Volume I was conducted by the Energy and Habitability Division (EH), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. E. M. Honig was the CERL Principal Investigator. Administrative support provided by Mr. R. G. Donaghy (Chief of EH) is acknowledged.

The principal investigation for Volume II of this report was conducted for CERL by Messrs. V. Bruce May, Craig L. Koralek, Subhash S. Patel and Dr. C. Leon Parker of Hittman Associates, Inc., Columbia, MD, under Contract No. DACA 88-76-C-0007.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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APPLICATION OF MODERN COAL TECHNOLOGIES
TO MILITARY FACILITIES
VOLUME I: SUMMARY OF FINDINGS

1 INTRODUCTION

Background

Coal was once widely used as a primary fuel in Army central heating and power plants. For environmental reasons, in the 1960's many plants were converted to cleaner fossil fuels: fuel oil and natural gas. Now, with the increasing scarcity and rising costs of these cleaner fuels, the Army faces the task of reconverting to coal, while simultaneously complying with stringent environmental limitations which encouraged the trend toward coal avoidance 15 years ago.

With the exceptions of Alaska and Europe, Army-wide use of coal is limited largely to industrial-type operations.[1] Much of the coal-burning equipment used previously at central heating and power plants is either no longer operable, technically outdated, or no longer in existence. Many existing boilers firing fuel oil and/or natural gas may require substantial modification to burn coal or coal-derived fuel.

To find economical, efficient, and environmentally sound solutions to increasing the use of coal, the Army is investigating advances made in the commercial sector on new coal utilization techniques. Of particular interest are gasification and liquefication techniques, which offer the potential for easy conversion of boilers from gas and oil to coal, and improved combustion techniques such as fluidized-bed combustion.

To date, most of the research and development in coal utilization has been in large utility-scale operations.[2] The Army would like to determine if any of these new developments offer technical and/or economic potential for future

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1 *Annual Summary of Operations - Fiscal Year 1975* (Department of the Army, 1976).

2 *Fossil Energy Program Report*, ERDA 76-10 (U.S. Energy Research and Development Administration, 1975-1976). pp 1-8.

military-scale application. The Army's needs differ from commercial needs in that an Army installation supports a relatively small population, rather than the large one of an urban area, so that furnaces of only modest capacity are required. Hence, coal-use technologies for military applications must be economically beneficial when operated on correspondingly modest scales. Moreover, the Army may be limited in the lack of qualified staff required to operate facilities using advanced coal technologies. Differences between military and commercial load profiles could require that military equipment have exceptional ability to operate at a lesser capacity. Operations and maintenance (O&M) of some advanced or "exotic" equipment may strain military O&M budgets, unless support such as a demonstration grant is provided.

Objective

The objectives of this study were (1) to assess the possible use of advanced coal utilization technologies at major Army installations, (2) to evaluate the economics and O&M impacts of using the technologies, and (3) to provide guidance to Facilities Engineering Directorate (Office of the Chief of Engineers) personnel on the application and costs of these technologies at Army bases.

Approach

This study used the following approach:

1. Information on energy requirements at Army installations with large gas/oil usage and large utility plants. was obtained for use in evaluating various coal-use technologies.

2. Information on the following existing and emerging coal-use technologies was obtained and evaluated: (a) flue gas cleaning, (b) coal pretreatment, (c) improved coal combustion methods, (d) coal gasification (low, medium and high Btu), (e) coal liquefaction.

3. The coal-use technolgies studied were evaluated against typical facility energy requirements; in addition, the technical performance potential, impact on existing facilities, environmental problems, impact on manpower requirements, impact on logistics, and construction and operating costs were determined.

Outline of Report

Chapter 2 discusses Army energy requirements at fixed facilities and technical and economic evaluation of coal use technologies appropriate to these needs. Chapter 3 presents conclusions on meeting Army energy needs with coal.

Mode of Technology Transfer

The results of this work will be incorporated into a new Engineer Technical Bulletin providing technical data and procedures necessary for preparing a project description, justification, and DD Form 1391 for application of advanced coal technology to Army installations.

2 DISCUSSION

Installation Energy Requirements

To determine whether application of coal-use technologies to military fixed facilities would be economical, the energy requirements of the 10 most energy-consumptive Army installations were examined (see Table 1). Ranking was by thermal-to-electrical demand ratio. Currently, the electrical demands are met by purchasing electrical energy from a commercial utility company, and thermal demands are met by boiler plants on post. A large thermal demand is evident at each post in Table 1, thus emphasizing the need for a fuel with reasonable cost and steady supply. Table 1 estimates the annual coal tonnages necessary to meet these thermal demands by using the standard conversion of 12,500 Btu/lb (29.07 MJ/kg) of coal. As shown in Table 1, the 10 largest Army energy users all use more than 50,000 tons/yr (45 000 t/yr) of coal; however most installations would use less than 100,000 tons/yr (90 000 t/yr). If coal use were combined with total or selective energy plants, coal use might increase by 12,000 to 36,000 tons/yr (10 800 to 32 400 t/yr).

Table 2 presents the same categories of FY75 information as shown in Table 1 for posts that will be using coal in FY78.[3] These installations are mostly industrial, in contrast to most of those in Table 1; i.e., other than Holston and Radford Army Ammunition Plants (AAPs), the coal-using posts for FY78 are not among the large energy-using posts. For the posts shown in Table 2, the coal tonnage equivalents of the FY75 annual thermal demand are more than 150,000 tons (135 000 t) for the two larger posts and between 9000 and 31,000 tons (8100 to 27 900 t) for the rest. This reflects the relatively low level of current Army coal consumption in comparison to other fuels and is to be contrasted with the data in Table 1, where even the lowest coal consumer has an equivalent tonnage of 60,000 tons (54 000 t), roughly twice that of the third highest coal consumer in Table 2. If the posts listed in Table 1 were to satisfy all their thermal demands by burning coal, then comparing the equivalent tonnages of Table 1 to those in Table 2 suggests that coal-handling facilities might have to be increased three to five times over current facilities to accommodate the greater coal usage.

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[3] Telecon 25 May 1977 between Mr. J. Donalley (OCE-FEU-M) and Dr. E. Honig (CERL-EH).

Table 1

Summary of Energy Requirements at 10 Army Installations*

Installation	Annual Electrical Demand $W\text{-}h \times 10^9$	Annual Electrical Demand $Btu \times 10^9$	Annual Thermal Demand $Btu \times 10^9$	Annual Thermal Demand $J \times 10^{12}$	Ratio of Thermal to Electrical Demand	Coal Tonnage Equivalent of Annual Thermal Demand k tons	Coal Tonnage Equivalent of Annual Thermal Demand (k ton-metric)
Holston AAP, TN	91	310	6007	6338	19.4	240	219
Radford AAP, VA	126	429	4908	5178	11.4	196	179
Fort Knox, KY	127	435	2604	2747	6.0	104	95
Aberdeen Proving Ground, MD	123	419	2463	2599	5.9	99	90
Fort Lewis, WA	141	480	2261	2386	4.7	90	82
Fort Benning, GA	151	516	2302	2429	4.5	92	84
Fort Bragg, NC	222	752	3054	3222	4.1	122	111
Fort Hood, TX	192	655	1892	1996	2.9	76	60
Redstone Arsenal, AL	263	899	2424	2558	2.7	97	88
Fort Mead, MD	218	744	1636	1726	2.2	65	59

*Data in first two columns are FY75 figures taken from *Facilities Engineering Annual Summary of Operations* (OCE, 1975).

Table 2

Summary of FY75 Energy Requirements for FY78 Coal-Using Army Installations*

Installation	Annual Electrical Demand		Annual Thermal Demand		Ratio of Thermal to Electrical Demand	Coal Tonnage Equivalent of Annual Thermal Demand	
	W-hx10^9	Btux10^9	Btux10^9	Jx10^{12}		k tons	(k ton-metric)
Holston AAP, TN	91	310	6007	6337	19.4	240	219
Radford AAP, VA	126	429	4908	5178	11.4	196	179
Rock Island Arsenal, IL	53	180	971	1024	5.4	39	36
Fort Benjamin Harrison, IN	50	170	698	736	4.1	28	26
Detroit Arsenal, MI	38	129	806	850	6.2	32	29
Tobyhanna AD, PA	18	61	616	650	10.1	25	23
Pueblo AD, CO	20	68	413	436	6.1	17	15
Anniston AD, AL	41	140	419	442	3.0	17	15
Michigan Army Missile Plant, MI	33	112	379	400	3.4	15	14
Lexington Blue Grass AD, KY	25	85	267	282	3.1	11	10

Data in first two columns are taken from** ***Facilities Engineering Annual Summary of Operations **(OCE, 1975).**

Coal-Use Technologies

Coal-use processes now being developed for commercial application are discussed briefly in this section; Volume II of this report provides a more detailed description.

Process and operating information was collected for 25 modern coal-use technologies (see Table 3). The technolgies were categorized according to the general nature of the coal-use process: low-Btu gasification, high-Btu gasification, liquefaction based on pyrolysis and hydrocarbonization, liquefaction based on hydrogenation, and direct combustion. Of the 25 processes shown in Table 3, five are in commercial operation, while the reminaing 20 are in various stages of development. All of the indirect processes evaluated convert coal, an inherently dirty fuel, into a relatively clean fuel which can be used as either a supplement to or a substitute for oil and natural gas as a boiler fuel.

Low-Btu Gasification

During gasification, coal is reacted with steam and oxygen. Particulates and condensibles from the reactor off-gas are removed by quenching, and sulfur compounds are removed later in the process. The crude gas has an as-fired heating value of 100 to 500 Btu/SCF* (560 to 7800 J/sm^3) and consists basically of H_2, CO, CO_2, CH_4, and H_2O. Crude low- and medium-Btu gas can be converted to a high-Btu gas having a heating value of up to 950 Btu/SCF (5335 J/sm^3), compared to approximately 1000 Btu/SCF (5615 J/sm^3) for natural gas. Although commercial low-Btu gasification plants exist, none are operational in the United States. Most developmental low-Btu coal gasification efforts in the United States have been developed to produce a fuel gas for high-temperature combined gas-steam turbine electric generators, to make fuel gas for captive industrial use, or to produce a synthesis gas for chemical processing. The major commercial processes for low- and medium-Btu gas production that are currently available include Lurgi, Winkler, and Koppers-Totzek.

Coal is converted to a low-Btu gaseous product in the Lurgi gasifier (Figure 1) by reaction with steam and air at approximately 250 to 300 (1.723×10^6 - 2.068×10^6 N/m^2) psi. The gasifier is a movingbed-type reactor with sized

*Standard cubic feet

Table 3

Modern Coal-Use Technologies: Processes and Status
(Metric Conversion Factor: 1 ton = .9 metric ton)

Low-Btu Gasification	
Lurgi	Commercially used since 1936
Koppers-Totzek	Commercial plants in existence
Winkler	16 plants in commercial operation
Wellman-Galusha	2 plants in commercial operation
Combustion-Engineering	5 TPH* demonstration unit scheduled for 1977
Westinghouse	0.6 TPH demonstration unit under construction
High-Btu Gasification	
Lurgi	Commercial and demonstration plants scheduled for 1978
CO_2 Acceptor	40 TPD+ pilot plant in operation
HYGAS	75 TPD pilot plant in operation
BIGAS	120 TPD pilot plant in construction
Synthane	75 TPD pilot plant in operation
Hydrane	26 TPD demonstration plant in design
Agglomerating Burner	25 TPD pilot plant in operation
Kellogg	Concept design
Liquefaction (Pyrolysis and Hydrocarbonization)	
Coed	36 TPD pilot plant in operation
Coalcon	2600 TPD demonstration plant scheduled for 1980
Fischer-Tropsch	One commercially operating plant
Liquefaction (Hydrogenation)	
SRC	2 pilot plants in operation
H-Coal	3 TPD bench plant in operation
Exxon Solvent Donor	1 TPD pilot plant in operation
Synthoil	10 TPD pilot plant in operation
Costeam	10 TPD demonstration plant under design
Direct Combustion	
Pulverized Coal	Many proven utility plants
Stoker-Fired Coal	Many proven utility and industrial plants
Fluidized Bed	Numerous demonstration plants in operation

*Tons per hour
+Tons per day

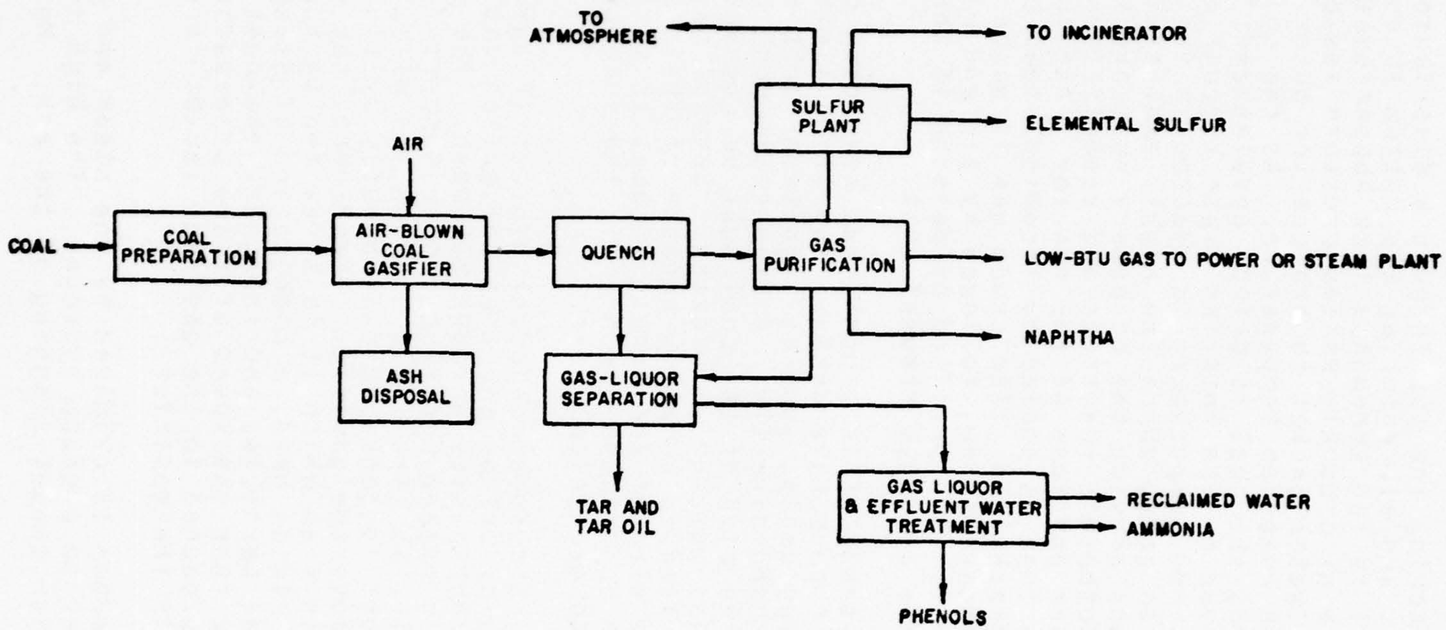

Figure 1. Lurgi low-Btu process.

coal entering the top through a distributor and a mixture of steam and air entering the bottom through a rotary-grate. The coal is fed through a lock hopper system. The gasifier consists of a double-walled pressure vessel. The inner wall forms a water jacket to protect the outer pressure wall from the high reaction temperature. As the coal charge travels downward, the coal is dried, devolatized, and gasified. Ash is removed by the rotating grate through a lock hopper system. The maximum temperature is reached in the combustion or oxidation zone, where the highly exothermic oxidation reactions provide the necessary heat and temperature for the endothermic reactions and vaporizations which occur in the upper portions of the reactor. Ash leaving the combustion zone is cooled by incoming steam and air before being discharged. The crude gas is washed and cooled by low-pressure steam, followed by air and water quench cooling. The gas is then purified by passing it through the hot carbonate acid gas removal unit.

Although this process has been used commercially since 1936, it does have certain operating limitations. Only noncaking coals, such as lignite or subbituminous coals, can be used directly. Caking coals must be pretreated before use. The size of the coal must be regulated closely, and all fines must be eliminated. Several gasifier units must be operated in parallel because of their small size. The maximum size of the Lurgi is about 12 ft (3.6 m) in diameter. Another operational problem is the susceptibility of moving parts to mechanical wear.

In the Koppers-Totzek process (Figure 2), coal is pretreated by drying and then pulverized until approximately 70 percent passes through 200 mesh. The drying medium, which is either hot flue gas or Koppers-Totzek gas burned with air, is circulated through the mill. The resulting coal dust is conveyed continuously by fluidization to service bins above the gasifier. From here, the coal passes to a feed bin from which it is screw fed to the mixing head. At the mixing head, a combination of steam and oxygen entrain the coal particles and transport the dust at velocities greater than the speed of flame propagation. Low-pressure steam produced in the gasifier jacket is used as the process steam in the gasifier.

Carbon is oxidized by the steam and air entering the gasifier to produce hydrogen. The high termperature of this operation causes slagging of the ash. More than half the

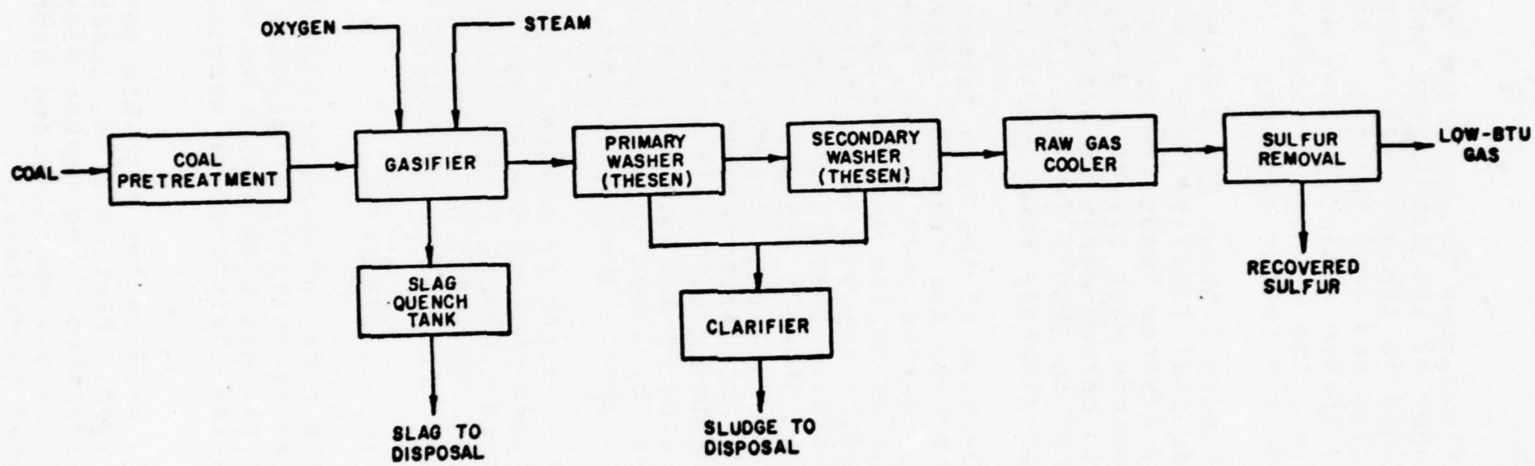

Figure 2. Koppers-Totzek low-Btu process.

slag flows down the gasifier walls into quench tanks. The remainder of the ash leaves the gasifier as a fine fly ash entrained in the exit gas. Water sprays remove the heavy particles and cool the gas. Final gas cleaning is accomplished by two Thesen disintegrators arranged in series. After compression, the gas is scrubbed with amine to remove hydrogen sulfide for sulfur recovery.

Figure 3 shows the Winkler fluidized-bed gasifier. Crushed coal (smaller than 1/4 in. [6 mm]) is dried and then fed by a screw feeder into the side of the reactor. Here the coal reacts with oxygen and steam to produce an off-gas rich in carbon monoxide and hydrogen. The fluid bed operates at 1500^o to 1850^{o}F (807 to 1000^{o}C), depending on coal type, at approximately atmospheric pressure.

Because of the high temperatures, all tars and heavy hydrocarbons are reacted. Approximately 70 percent of the ash is carried over by gas, and 30 percent is removed from the bottom of the gasifier by the ash screw. Unreacted carbon carried by the gas is converted to carbon monoxide hydrogen by secondary steam and oxygen in the space above the fluidized bed. To prevent ash particles from melting and forming deposits in the exit duct, the gas is cooled by the radiant boiler section before it leaves the gasifier. Raw gas leaving the gasifier is passed through an additional waste-heat recovery section. Fly ash is removed by cyclones, followed by a wet scrubber, and finally an electrostatic precipitator. The gas is then compressed and purified.

The amount of oxygen consumed by the Winkler process is between that of the moving-bed Lurgi and the entrained-bed Koppers-Totzek. The Winkler does not produce the tars, phenols, and light oils that the Lurgi does; however, it has been operated commercially only at atmospheric pressure.

High-Btu Gasification

The final product of high-Btu gasification processes is composed essentially of methane (CH_4) and can be transported in natural gas pipelines. No modifications to natural gas combustion equipment are necessary to use synthetic high-Btu gas.

To produce the high-Btu gas, coal is reacted with steam and oxygen. Particulates, condensables, and sulfur compounds are eliminated. The carbon dioxide ratio is adjusted to 3 to 1, and the carbon monoxide and hydrogen are then catalytically connected to methane.

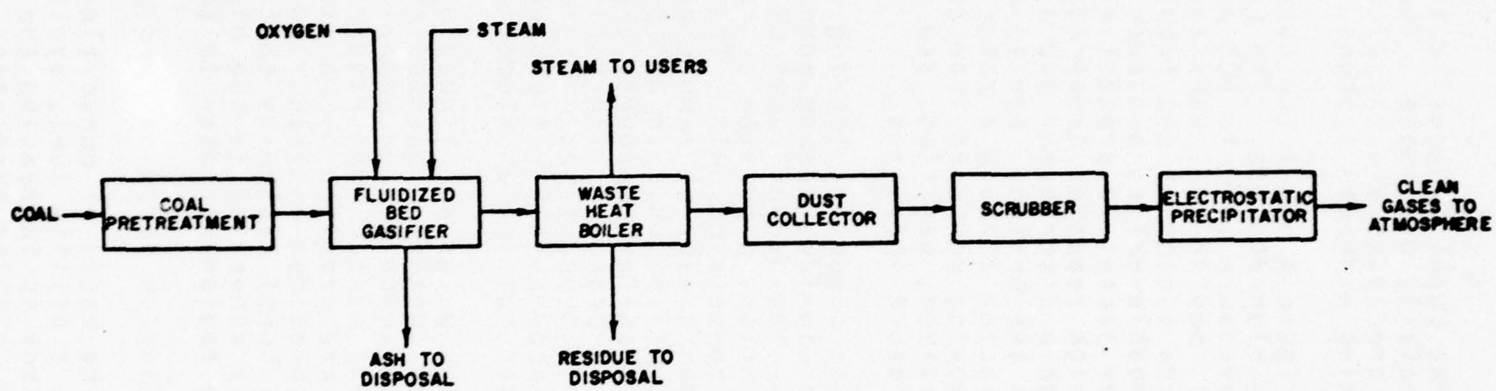

Figure 3. Winkler low-Btu process.

The Lurgi process is the only high-Btu system now commercially available. The CO_2 Acceptor, Synthane, and HYGAS processes are the closest to commercialization of the remaining high-Btu systems.

Figure 4 shows the Lurgi gasification process for producing high-Btu gas. The Lurgi gasifier is classified as a high-pressure (300 to 500 psig [2.068×10^6 - 3.477×10^6 N/m^2]), moving-bed, nonslagging, steam-oxygen system that produces synthesis gas from coal. The equipment consists of a double-walled pressure vessel, in which the walls form a water jacket to protect the outer pressure vessel wall from high reaction temperatures. Sized coal enters the top through a distributor and a mixture of steam and oxygen enters the bottom. Ash is discharged from the bottom of the reactor through a rotating grate into a lock hopper. Coal moving downward from the top of the reactor is dried, devolatized, gasified, and oxidized in succession as the temperature increases.

Hot crude gas leaving the gasifier contains primarily carbon dioxide, carbon monoxide, hydrogen, and methane. To achieve the proper ratio of carbon monoxide and hydrogen for methanation, a portion of the crude gas is passed through a shift conversion unit. The converted gas and the bypass are then cooled to remove water and liquid byproducts before gas purification. In gas purification, carbon dioxide and gaseous sulfur compounds are removed from the gas by the Rectisol process. The purified gas is then methanated to high-Btu product gas. The waste gas produced by Rectisol is treated by a Stretford unit to recover the byproduct hydrogen sulfied as elemental sulfur.

The water and liquid byproducts removed from the crude gas are further processed to recover tar, tar oil, crude phenol, ammonia, and water for the cooling system and other in-plant uses. Fuel requirements for the plant and process steam are provided by an air-blown coal-gasification unit which provides a clean, low-heating-value gas. An advantage of the Lurgi system is that the low-Btu process can be readily converted to the high-Btu process by addition of proven equipment later in the system.

Liquefaction Based on Pyrolysis and Hydrocarbonization

The basis of converting coal into a liquified fuel for use as a utility fuel, synthetic crude oil, and/or petroleum feedstock is increasing the weight ratio of hydrogen to carbon. During pyrolysis, coal is heated in the absence of

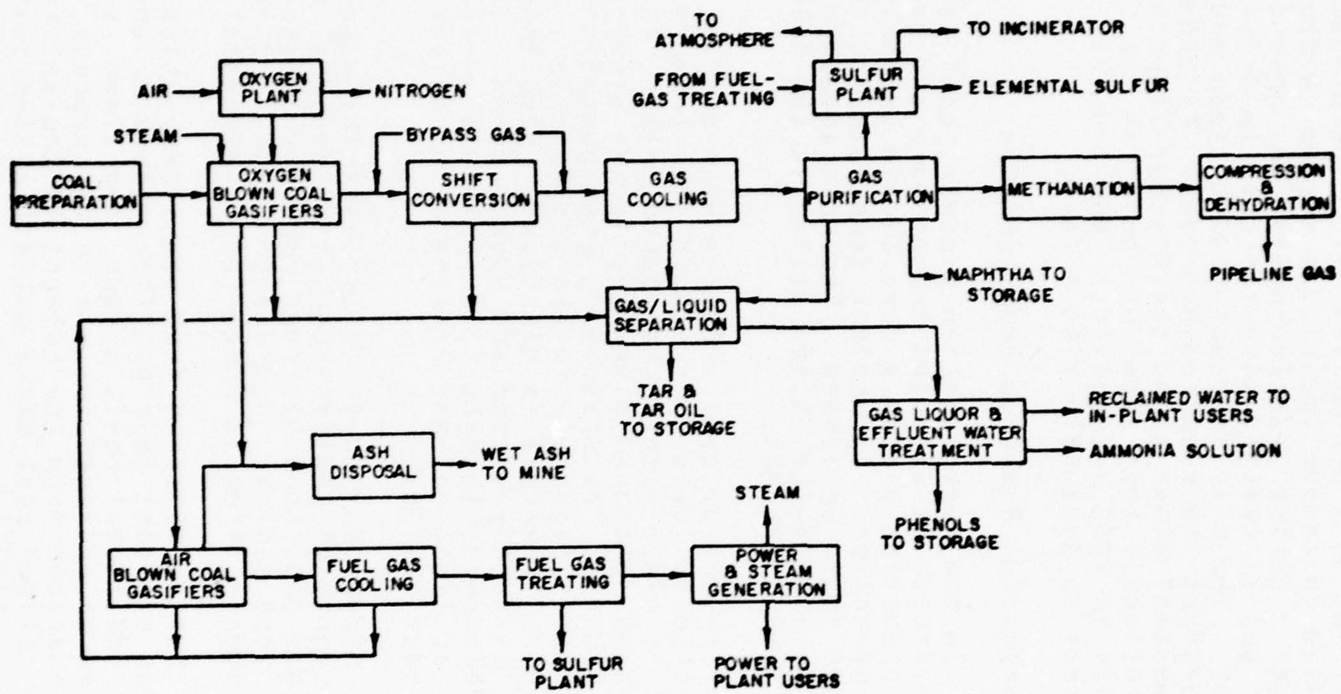

Figure 4. Lurgi high-Btu process.

direct contact with hydrogen. Volatile matter and naturally occurring oils are driven off. The product oil is hydrotreated to remove impurities such as nitrogen, sulfur, and oxygen. During hydrocarbonization, however, heated hydrogen-rich gas is reacted with the coal to drive off volatile gases. The char is reacted with steam and air (or oxygen) to produce the required hydrogen. As shown in Table 3, one commercial plant using the Fischer-Tropsch process is operational; this plant was built in the Union of South Africa in 1957 and converts 6600 tons/day (5940 t/day) of coal to synthetic liquid fuel.

Liquefaction Based on Hydrogenation

In the hydrogenation process, coal is directly exposed to hydrogen at elevated temperature and pressure. Catalytic hydrogenation yields a more liquid product than noncatalytic hydrogenation. At ambient temperatures, the product may be either solid or liquid. The most advanced liquefaction technology in the United States is the Solvent Refined Coal (SRC) process.

The SRC process converts high-sulfur, high-ash coal to ashless, low-sulfur liquid fuel (Figure 5). Pulverized coal is mixed with a coal-based solvent in a slurry tank. Hydrogen, produced elsewhere in the process, is combined with the slurry. The mixture is then pumped through a preheater and into a dissolver, where approximately 90 percent of the dry, ash-free coal is dissolved. Simultaneously, the coal is depolymerized and hydrogenated. The solvent is hydrocracked, forming lower molecular weight hydrocarbons such as light oil and methane. The sulfur is removed as hydrogen sulfide.

After leaving the dissolver, the gases are separated from the slurry of undissolved solids and coal oil solution. The raw gas goes to a hydrogen recovery and gas desulfurization coal feed slurry. Hydrocarbon gases are released and the hydrogen sulfide is converted to elemental sulfur.

Solids filtered from the slurry which contain unreacted carbon are sent to a gasifier-converter where they are combined with additional coal, oxygen, and steam, and thereby converted to hydrogen for use in the process. The refined coal is separated from the solvent in the solvent recovery unit. This refined coal has a solidification point of 350 to 400°F (175 to 202°C).

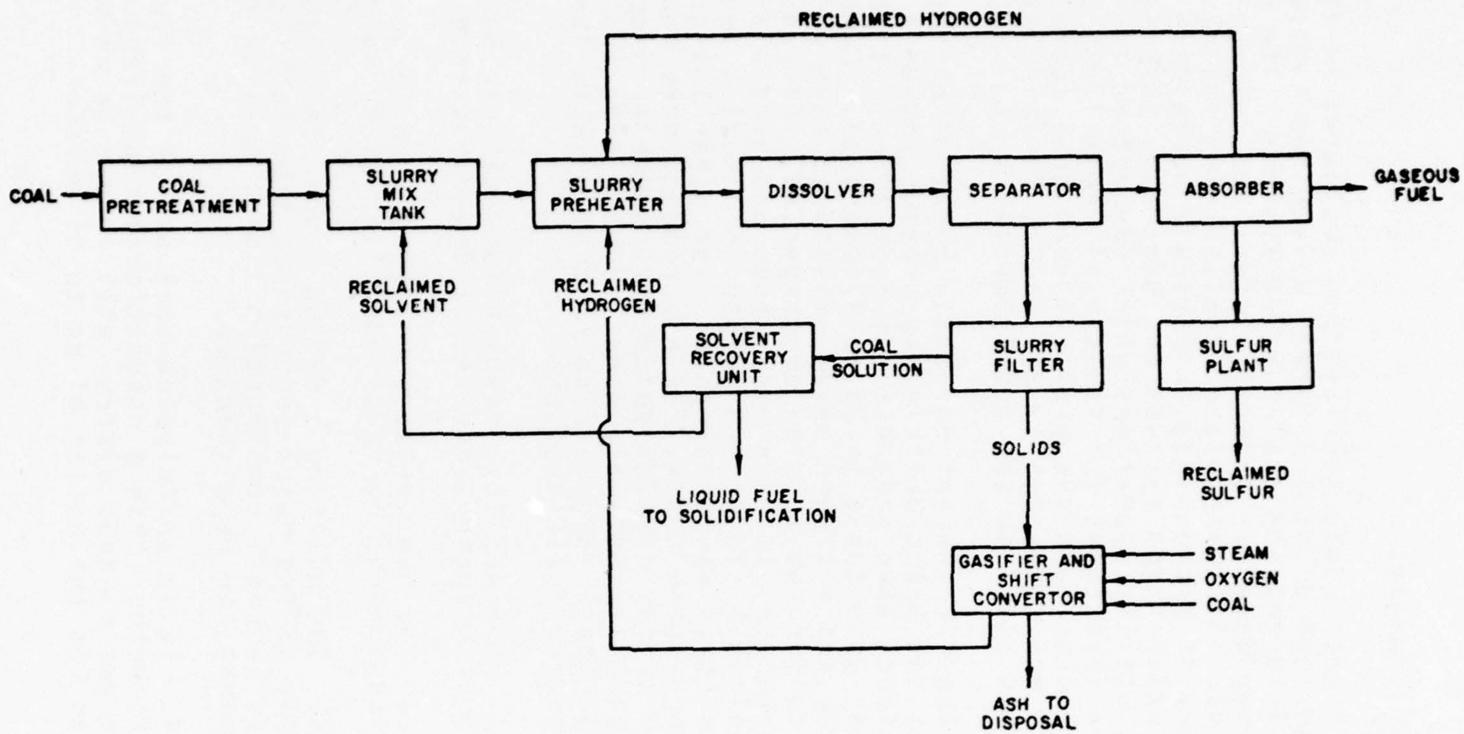

Figure 5. Solvent refined coal process.

Direct Combustion

Direct combustion systems evaluated in this study were categorized as stoker-fired, pulverized (suspension-fired), and fluidized-bed coal-burning systems. The principal distinction made was between stoker- and suspension-firing systems. Stoker-equipped coal-burning boilers have a long history of proven industrial-scale operation; however, suspension-fired systems are generally more applicable to large utility operations which can afford the substantially larger investment for additional capital equipment. While both stoker- and suspension-firing coal technolgies are proven and commercially available, fluidized-bed combustion (FBC) is still in the developmental stage.

The FBC concept currently being developed in the United States and Great Britain may provide higher energy conversion efficiency than conventional coal-fired systems (up to 40 percent as opposed to 33 to 37 percent). Lower sulfur dioxide and nitrogen oxide emissions, even when burning high-sulfur coals, also are expected. FBC equipment has the potential to burn many types and grades of coal as well as municipal sludge and refuse, oil shale, industrial and agricultural waste materials, and other low-grade fuels. In bench-scale tests, FBC has removed more than 90 percent of the sulfur dioxide pollutants normally expected from coal. This may eliminate the need for expensive and massive sulfur dioxide stack gas cleaning or coal desulfurization. Other advantages of FBC include:

1. Low-quality, high-sulfur coal can be burned without danger of slagging, because of low combustion temperatures.

2. The heat release and heat transfer coefficients are high, thus reducing required boiler size, weight, and cost.

3. The multi-cell design lends itself to mass production assembly of the major components, thus facilitating shipping and saving plant construction time. On-site fabrication of components can be eliminated.

4. It is anticipated that use of the fluidized-bed boiler, rather than a conventional coal-fired boiler requiring a flue gas cleanup system, will result in an overall cost savings for the boiler of up to 35 percent.

5. The overall operating efficiency of the multi-cell fluidized-bed boiler power plant is projected to be 39 percent as compared to approximately 37 percent for a conventional coal-fired plant with stack gas cleanup equipment.

In a fluidized-bed boiler, small particles of a limestone or dolomite sorbent are fluidized by hot air. This fluidized bed is heated to approximately 1600°F (862°C), and finely crushed coal is fed into it. The feed rate is such that the amount of combustible material in the bed is usually less than 1 percent. Turndown is accomplished by reducing air and coal flow into the bed. The sulfur in the coal which is eliminated as sulfur dioxide is captured by the sorbent as calcium sulfate. Powdered dolomite or limestone sorbent is continuously removed. The low combustion temperature minimizes formation of nitrogen oxides and prevents ash agglomeration. Calcium sulfate is discharged with the ash.

Pressurized fluidized-bed systems are in an earlier stage of development than nonpressurized systems and in the future may provide additional economic savings and increased thermal efficiency. The furnace size can be reduced because of decreased gas volume, and additional sulfur dioxide can be removed, reducing the need for sophisticated pollution control devices. However, the units appear more appropriate for larger installations' (200 MW or greater) power plants.

Table 4 lists the major applications of commercial industrial-scale coal combustion equipment. As shown, suspension-firing systems are applicable only at the upper limit of industrial-scale steam-generation requirements.

Selection of Coal-Use Technologies

Applicable coal-use technologies were selected from those commercially available to the Army (Table 3) by evaluating the technical factors relevant to implementing a given process on the military-industrial scale. Volume II provides details of the evaluation. This selection procedure was not optimized to obtain a single process or even one process from each technology, but rather to identify within the technologies those processes which appear applicable and to eliminate unqualified technologies or processes. Economic factors were used to assist in identifying or eliminating coal-use technologies and processes which were deemed potentially applicable from a technical standpoint.

Table 4

Applications of Industrial Coal Combustion Equipment

Firing Method	Maximum Burning Rate Btu/hr-ft^2 (J/hr-m^2)	Typical Boiler Capacity Range in Pounds/Hour Steam (kg/hour)			
		Anthracite	Caking Bituminous Eastern Area	Free-Burning Bituminous Midwestern Area	Subbituminous and Lignitic Western Area
Spreader Stokers					
Stationary and Dumping Grate	450,000 (770 000)	-	5,000-150,000 (2 250-68 000)	5,000-150,000 (2 250-68 000)	5,000-150,000 (2 250-68 000)
Traveling Grate	750,000 (1283 400)	-	5,000-200,000 (2 250-90 700)	5,000-200,000 (2 250-90 700)	5,000-200,000 (2 250-68 000)
Vibrating Grate	400,000 (684 450)	-	5,000-200,000 (2 250-90 700)	5,000-200,000 (2 250-90 700)	5,000-200,000 (2 250-90 700)
Underfeed Stokers					
Single and Double Retort	400,000 (684 450)	1,000-10,000 (450-4 500)	1,000-35,000 (450-15 875)	5,000-30,000 (2 250-13 600)	-
Multiple Retort	600,000 (1026 700)	-	30,000-500,000 (13 600-226 800)	-	-
Overfeed Stokers					
Chain Grate	500,000 (855 600)	-	-	10,000-200,000 (4 500-90 700)	-
Traveling Grate	500,000 (855 600)	10,000-200,000 (4 500-90 700)	10,000-200,000 (4 500-90 700)	-	10,000-200,000 (4 500-90 700)
Vibrating Grate	400,000 (684 450)	-	-	-	
Suspension Firing					
Pulverized Coal	-	60,000-1,000,000 (27 200-453 600)	60,000-1,000,000+ (27 200-453 600)	60,000-1,000,000+ (27 200-453 600)	60,000-1,000,000+ (27 200-453 600)
Cyclone Furnace	-	-	75,000-350,000 (34 000-159 000)	75,000-350,000 (34 000-159 000)	75,000-350,000 (34 000-159 000)

Definition of Technical and Economic Criteria

Specific technical criteria considered in the selection of coal-use technologies were process design factors, capacity, coal supply, and environmental factors. Table 5 provides a synopsis of the technical criteria, and Table 6 summarizes economic criteria used to evaluate the coal-use technologies. Volume II provides a more detailed discussion of both the technical and economic factors.

Application of Technical and Economic Criteria

Tables 7, 8, and 9 summarize the characteristics which will have the greatest influence on military-scale use of the four most advanced commercial low-Btu coal gasification processes. On the basis of these summary tables, the Lurgi and Koppers-Totzek processes appear to be the most promising processes for near-term Army use.

For production of low-Btu gas, Koppers-Totzek-based systems have sufficiently high temperatures to minimize formation of oils and tar, and do not require high-pressure operation; however, the need for an oxygen plant to supply the gasifier with oxygen is a disadvantage. The Lurgi System has the advantages of being able to produce low-Btu gas using either air or oxygen as the oxidizing medium and of having a high thermal efficiency. Its prime disadvantage is the lower temperature operation which causes the formation of oils, tars, and phenols which must be separated from the raw gas and then disposed of. The Lurgi process appears to have lower capital costs than the Koppers-Totzek process. The Winkler process shows potential for long-term Army use; however, its complex fluidized-bed process and potential problems in downscaling to meet installation energy load levels will probably prevent its near-term use.

While several low-Btu and medium-Btu processes are under development, the bases of these technologies are combined high-temperature gas and steam-turbine electric power generation. The scale of these units is not compatible with foreseeable Army needs.

All high-Btu processes must be considered developmental. Tables 10 and 11 summarize the relevant characteristics of the most promising and most advanced of these systems. The oxygen-fired Lurgi process is the only fixed-bed system,

Table 5

Technical Criteria for Evaluating Modern Coal-Use Technologies

Process Factors	Coal Supply Factors
Product/Use Capability	Geography/Location
Product Storage and Delivery	Coal Rank and Properties
Process Complexity	Process Requirements
Process Reliability	Long-Term Availability
Adaptability to Feedstock Variation	Ash and Sulfur Content
Conversion Efficiency	
Process Water Requirements	
Ability to Convert Waste Products	**Environmental Factors**
	Ash Disposal
Capacity Factors	Other Solid Waste
	Air Pollution
Base Load	Wastewater
Peak Load	Environmental Regulations
Turndown Flexibility	
Ability to Meet Changing Demand	

Table 6

Economic Criteria for Evaluating Modern Coal-Use Technologies

Capital Costs

Other Initial Costs

Operating Costs

Labor Requirement

Byproduct Value

Transportation

Table 7

Product Factors Affecting the Low-Btu Gas Applicability to Army Bases

Gasifier	Oxidizer **	Typical Gas Compositions, Mole Percent* CO	CH_4	H_2	H_2/CO	Suitability For Upgrading to High-Btu Gas	Need for Pressurization Before Distribution	Volume Ratio of Gas Relati[illegible] to Natural G[illegible]
Lurgi	A	9.2	4.7	20.1	2.2	No	No	5.6
	O	13.3	5.5	19.6	1.5	Yes	No	3.1
Koppers-Totzek	O	50.4	0.0	33.3	0.7	No	Yes	3.3
Winkler	A	25.7	0.7	30.3	1.1	No	Yes	8.3
	O	19.0	2.5	13.9	0.7	No	Yes	3.3
Wellman-Galusha	A	29.6	2.4	32.2	1.1	No	Yes	5.9
	O	26.0	0.5	11.7	0.6	No	Yes	3.6

* CO_2, N_2, H_2O and other constituents are not listed.
\+ Natural Gas, 1000 Btu/scf
** A: Air, O: Oxygen

Table 8

Equipment Factors Affecting Applicability of Low-Btu Gas to Army Use

Gasifier	Gasifier Description			Gasifier Performance								
	Type	Coal Feed Capabilities	Gasifying Medium	Operating Pressure atm	Gasifier Diameter ft	Unit Capacity Billion Btu/Day	Heating Value Btu/scf	Turn-down	Efficiency Cold (Percent)	Efficiency Hot (Percent)	Steam Requirement lb/MBtu	Units Required for Army-Scale Use
Lurgi	Fixed/ agitator	Needs sized low-caking and non-caking coals	(A) Steam-air and (B) Steam-oxygen	20	12 16 (planned)	7 to 9 12 to 16	180 (air) 320 (oxygen)	50	91	82	150 to 180	2 to 10
Koppers-Totzek	Entrained slagging	Needs pulverized coals Can accept all types	(A) Steam-oxygen (B) Air cannot be used	1	2 burners* 4 burners	7 to 9 14 to 18	300.	35 65	86	67	40 to 65	1 to 3
Winkler	Fluidized	Needs crushed low-caking and noncaking coals	(A) Steam-air (B) Steam-oxygen	1	18	8 to 10	120 (air) 300 (oxygen)	53	75	65	20 to 30	2 to 3
Wellman	Fixed/ agitator	Needs sized low caking and non-caking coals	(A) Steam-air (B) Steam-oxygen	1	10	15 to 20	170 (air) 200 (oxygen)	90	95	82	60 to 75	10 to 15

* Not cylindrical; 25-ft (7.5m) ellipsoidal

Table 9

Product, By-Product, and Waste Factors of Low-Btu Gasification Processes

Process	By-Products	Environmental Considerations	Remarks
Lurgi	Tar, oil, phenols, ammonia, steam	Will require a gas cleanup and wastewater treatment facility	Suitable for industrial heating. Combined-cycle operation is not simple. Instrument control simple.
Koppers-Totzek	Steam	Purification system is less complicated since only trace amounts of tar, oil, and phenols are present in the gas	Suitable for combined-cycle operation. Instrument control sophisticated.
Winkler	Steam	Purification system is less complicated since only trace amounts of tar, oil, and phenols are present in the gas	Suitable for industrial heating and combined-cycle operation. Instrument control sophisticated.
Wellman-Galusha	Tar, oil, phenols, ammonia, steam	Will require a gas cleanup and wastewater treatment facility	Suitable for industrial heating. Combined-cycle operation simple. Instrument control simple.

and the HYGAS and CO_2 Acceptor processes do not require oxygen; however, the latter two processes suffer the disadvantage of extremely complex solids transfer in a high-temperature environment. Other disadvantages include the high concentrations of methane produced in the gasifier and problems of scaledown from the larger commercial sizes. Pilot plant sizes do produce gas in quantities required by Army facilities, but costs may be prohibitive.

All high-Btu processess require steam (the source of hydrogen), carbon dioxide and hydrogen sulfide removal, and methanation. For military uses, production of high-Btu gas may require excessively sophisticated equipment compared to other available options.

Of the processes shown in Tables 10 and 11, the Lurgi system is closest to commercialization for production of high-Btu gas. It also has the least sophisticated technology but requires (as does the low-Btu version) fairly extensive waste control. Shift, gas cleanup, and methanation all are necessary processing steps for upgrading the raw gas to a high-Btu product. The Synthane, BIGAS, HYGAS, and CO_2 Acceptor processes are considered second-generation technologies. Oxygen is required by the Synthane reaction. Hydrogen must be supplied separately to HYGAS, although sufficient hydrogen can be generated in the CO_2 Acceptor reactor to avoid this. All four systems require methanation, but the highest concentration of methane, and therefore the least additional methanation reaction, is obtained with HYGAS. The BIGAS and CO_2 Acceptor systems are the "cleanest" of the processes.

The data indicate that the high-Btu gasification process most likely to be compatible for Army use in the near future is the Lurgi. The CO_2 Acceptor and HYGAS, which are the two most advanced second-generation processes, may be considered but with reservations because of the complexity of their equipment.

There are currently no commercial coal liquefaction processes in the United States. All such processes are under development and will not become commercial in the near future. These systems are characterized by complex unit processes. New technology is required in the initial breakdown of coal

Table 10

Product and Process Factors Affecting Applicability of High-Btu Gas to Army Use

	Typical Raw Gas Compositions, Mole Percent						
	CH_4	CO	H_2	Ratio of H_2/CO	Quench and Heat Recovery	Gas Cleanup System	Shift Reaction
Lurgi	4.7	9.2	20.1	2.2	Gas washed with gas liquor	Not required prior to shift reaction; required prior to methanation step	About 50% of the gas bypasses shift reaction
Synthane	15.4	10.5	17.5	1.7	Gas washed with water	Not required prior to shift reaction; required prior to methanation step	Part of the gas bypasses shift reaction
BIGAS	8.1	22.9	12.7	0.6	Gas washed with hot condensate	Not required prior to shift reaction; required prior to methanation step	All the crude gas goes to shift reaction
HYGAS	32.8	11.6	37.6	3.1	Gas washed with water or oil	Required prior to methanation step	Not required, since H_2/CO ratio after gas cleanup is 3.1; ratio adjusted by hydrogen addition if required
CO_2 Acceptor	17.3	14.1	44.6	3.2	Gas washed with water	Smaller system required due to H_2S and CO_2 reaction with the acceptor	Not required since raw gas contains enough hydrogen

Table 11

Equipment Factors Affecting Applicability of High-Btu Gas to Army Use
(Metric Conversion Factors: 1 gal/million Btus = 15.02 l/Kgc;
1 Btu/SCF = 37245.8 J/sm^3)

Process	Bed Type	Coal Feed Capabilities and Pretreatment	Feed System	Pressure atm	Exit Gas Temperature °F(°C)
Lurgi	Fixed Agitator	Limited to noncaking or low-caking coals. Fine coal sizes must be formed into briquettes.	Pressurized lock-hopper system	20 to 30	700 - 1100 (367 - 587°C)
Synthane	Two-stage fluid bed	Caking coal pretreated in a separate high-pressure fluidized bed. Wide range of coal, including lignite, can be used.	Pressurized lock-hopper system	70	1400 (752°C)
BIGAS	Entrained/ slagging	All types of coals can be used without prior treatment.	Coal water slurry	100	1700 (917°C)
HYGAS	Three-stage fluid bed	Caking coal pretreated in a separate-atmosphere fluidized bed.	Coal oil slurry	70	1200 (542°C)
CO_2 Acceptor	Single-stage fluid bed	Caking coal pretreated in a separate fluidized bed. Limited to more reactive lignite and subbituminous coals.	Lock-hopper system	10-20	1500 (807°C)

Table 11 (Cont'd)

Process	Methanation and Dehydration	Oxygen Plant	Process Water Requirements Gal/Million Btu	Thermal Efficiency Percent	Heating Value Btu/SCF
Lurgi	Methanation larger than HYGAS process	Required	3.4	67	980
Synthane	Methanation smaller due to high percent of methane produced on the gasifier	Required due to high CO_2 production in the gasifier	4.3	65	927
BIGAS	Large methanator required due to small H_2/CO ratio	Large plant required	6.4	69	943
HYGAS	Methanator smaller due to high percent of methane produced in hydrogasifier	Not required	7.6 (Steam-Oxygen)	57 (Steam-Iron) 71 (Steam-Oxygen)	941 (Steam-Iron) 947 (Steam-Oxygen)
CO_2 Acceptor	Large methanator required since amount of methane produced directly is low	Not required	6.3	62.5	953

into liquid components. Subsequent processing steps resemble oil-refining operations and the nature of the processing equipment and the technology dictates that large-scale facilities will be necessary to economically produce liquid fuels from coal. In general, a minimum economic capacity is nominally 50,000 barrels per day of product from 18,000 to 25,000 TPD (16 200 to 22 500 t) of coal. This far exceeds the consumption of any individual military facility. Even the major energy-consuming bases use only one-twentieth to one-fortieth the Btu equivalent of this amount of oil.

None of the coal liquefaction technologies under development can be selected for further study because of the large amount of production required for their economical operation. Additional factors in eliminating these processes are disposal of the multiple byproducts they produce and the complexity of the technology. If the processes were scaled down to requisite size, the operation would be similar to a small petrochemicals plant. Except for the capacity restriction, Solvent Refined Coal (SRC), H-coal, and Coalcon processes would be the most promising liquefaction processes. It is possible that future developments may result in liquefaction processes compatible with Army facilities' fuel capacity needs. At this time, however, no such processes have been identified.

Every commercial direct combustion technology evaluation could conceivably be applied at military installations. Table 12 lists the advantages and disadvantages of each system. The only advanced developmental technology for direct coal combustion is the fluidized-bed system.

Evaluation of different stoker technologies indicates that each could be applied at military installations. Each is efficient and reliable, adaptable to burning most types of coals, and compatible with required load demands and variations. Environmental problems, stack gas emissions, or ash disposal are manageable.

Pulverized coal combustion could also be effective at military installations. Despite the fact that coal pulverization equipment is necessary, energy efficiency, size compatibility, and turndown capability through use of multiple units may make pulverized coal systems attractive to installations with sufficiently large consistent central steam loads to

Table 12

Summary of Factors in Direct Coal Combustion Application

Technology	Status	Capacity	Economics	Air Pollution	Fuel
Spreader Stoker	Highly reliable. Requires minimal space, efficient.	Boiler Capacity: 75,000 to 400,000 lb steam/hr (21 307 to 113 640 kW). Responsive to variations in load demands.		Dust collectors, SO_2 control, and ash disposal necessary.	Can burn broad range of fuels including caking coals - no anthracite. Coal size segregation important.
Underfeed Stoker	Efficient.	Outputs up to 500,000 Btu/sq ft-hr (5677 mJ/m^2-hr) and steam capacity from 30,000 lb/hr (8510 kW) for single retort to 500,000 lb/hr (142 000 kW) for multiple retort. Can be designed to handle variations in load.		Particulate, SO_2, and ash disposal necessary.	Coal size effects capacity and efficiency. Can burn caking coals as well as others. Coal size segregation important.
Water-Cooled Vibrating	Becoming increasingly popular. Efficient.	Output: up to 400,000 Btu/sq ft-hr (4541.6 mJ/m^2-hr) and steam capacity up to 100,000 lb/hr (28 400 kW)		Especially adaptable to multiple fuel firing. Particulate and SO_2 removal equipment required. Ash disposal necessary.	Low- and high-rank can both be burned. Can burn coals with high free-swelling index.
Chain Grate and Traveling Grate Stokers	Relatively high maintenance. Efficient.	Output: 350,000 to 500,000 Btu/sq ft-hr (3974 to 5677 mJ/m^2-hr) and steam capacity up 100,000 lb/hr (28 400 kW).		Minimum of fly ash carryover. SO_2 and particulate control equipment necessary.	Can burn nearly any solid fuel. Coal size aggregate important.

Table 12 (Cont'd)

Technology	Status	Capacity	Economics	Air Pollution	Fuel
Pulverized Coal: Bin System	Pulverized system required. More efficient than stokers. 400,000 lb/steam hr (113 640 kW) output is generally used in large utility scale furnaces for electric power production.		No longer competitive with direct firing.	Danger of explosion during storage and crushing of coal. Requires SO_2 and particulate control equipment.	Can burn all ranks of bituminous - anthracite with special preparation.
Pulverized Coal: Direct Firing System	Pulverizer system required. Must be operated continuously. More efficient than stokers above 400,000 lb (160 00 Kg) steam/hr. Greater simplicity than bin system.	Multiple pulverizers and burners permit adjustment to demand. Generally used in large utility boilers for electric power production.	Lower initial cost than bin system.	Requires SO_2 and particulate control equipment.	
Multi-Cell Fluidized Bed	Most efficient method of direct combustion. Technology in developmental stage.	Multiple modules permit adjustment to demand. Steam capacity undeterminal since equipment is developmental.	Inexpensive due to fabrication potential.	Reduced SO_2 (up to 90 percent) and no emissions. Ash is sintered and can be used as an aggregate.	Can burn any coal and other solid fuels. No danger of slagging.
Coal/Oil Slurry	Technology in developmental stage.	Won't significantly affect Btu output when oil-fired unit is converted. Can be fired in many identical boilers designed for heavy oil and coal.	Increase in capital cost and operating costs.	No significant effect on emmissions.	

justify the larger capital investment. As with stokers, environmental impact should be minimal if there is proper preparation and control.

Fluidized-bed combustion (FBC) demonstration plants currently are being funded by the Energy Research and Development Administration (ERDA). This technology promises to be an effective, efficient, economical, and environmentally sound method of burning coal. Variations in load demand and sizing are easily met with this method. Another significant advantage is elimination of the necessity for coal desulfurization and/or sulfur dioxide stack gas cleaning. Whether FBC will be available for near-term Army use depends on the performance of demonstration plants.

Table 13 shows the general economy of each of the coal-use systems found to have technical potential for installation use. The data shown are accurate only in general terms and are highly variable; precise data can be obtained only by conducting an in-depth study of the technical and economic feasibility of using a given system at a specific site. Although projected capital and operating costs for coal gasification systems show potential when applied to installations having large energy loads, more specific information on costs and operational problems is needed to confirm present estimates and to permit extrapolation of the data to smaller systems.

Table 13

Capital and Annual Costs of Currently and Near-Term Available Coal-Use Technologies for Military Installations (New Plants Only)*

Process	Costs	
	$/kBtu-hr Input ($/MJ-hr Input) Capital	$/M Btu-hr Input ($/GJ-hr Input) Annual (Operating)
Lurgi Low-Btu Gasification**	8.10 (7.68)	2.20 (2.09)
Koppers-Totzek Low-Btu Gasification**	14.50 (13.75)	Not Available
Lurgi High-Btu Gasification**	16.40 (15.55)	3.00 (2.84)
Pulverized Coal Firing+	26.00 (24.65)	6.35 (6.02)
Stoker Coal Firing+	21.00 (19.91)	5.25 (4.98)

*Cost based on 5×10^{12} Btu/year plant capacity using bituminous coal. For details, see Volume II. (8×10^{11} Joule/year)

**Costs exclude combustion hardware and fuel handling.

+Costs for new combustion equipment.

3 CONCLUSIONS

Stoker- and pulverized-firing of coal are technologies that can be applied currently and in the near-term. Fluidized-bed combustion may become a prospect for direct combustion in the near term if current developmental plants show successsful operation.

Capital costs for direct coal combustion technologies (based on 5 x 10^{12} Btu/yr [8 x 10^{11} J/yr] plant input capacity using bituminous coal) available for Army use are: stoker-firing, $21.00/kBtu-hr ($19.91/MJ-hr); and pulverized-firing, $26.00/kBtu-hr ($24.65/MJ-hr). Annual operating costs of direct combustion technologies are: stoker-firing, $5.25/MBtu-hr ($4.98/GJ-hr); pulverized-firing, $6.35/MBtu-hr ($6.02/GJ-hr).

Current and near-term Army-scale coal gasification prospects are the Lurgi and Koppers-Totzek low-Btu processes and the Lurgi high-Btu process. Existing natural gas- and oil-fired boilers can be adapted to low-Btu coal-derived gas firing by burner modification, and high-Btu gas may be directly substituted for natural gas.

Capital costs of coal gasification techniques (based on 5 x 10^{12} Btu/yr input using bituminous coal) are: Lurgi low-Btu, $8.10/kBtu-hr ($7.68/MJ-hr); Koppers-Totzek low-Btu, $14.50/kBtu-hr ($13.75/MJ-hr); Lurgi high-Btu, $16.40/kBtu-hr ($15.55/MJ-hr). Estimated annual operating costs under the same conditions are Lurgi low-Btu, $2.20/MBtu-hr ($2.09/GJ-hr); and Lurgi high-Btu, $3.00/MBtu-hr ($2.84/GJ-hr). Operating costs of the Koppers-Totzek process are not available. All costs are current (FY77) dollars; the cost of using a given technology at a specific installation will vary, depending on site-specific factors.

Fluidized-bed combustion will be available only in the long term. Long-term coal gasification prospects appear to rest with the CO_2-Acceptor high-Btu gasification process.

No coal liquefaction processes appear to be economically feasible at their current stage of development for Army-scale applications.

The Winkler fluidized-bed, low-Btu gasification process will not be available for installation use until scaledown problems have been identified and resolved.

The projected capital and operating cost estimates for coal gasification systems show potential economic benefit

when applied to the maximum Army size range (5×10^{12} Btu/yr [8×10^{11}/yr]). More specific information on costs and operational problems is needed to confirm the present estimates and to permit confident extrapolation of the data to smaller systems.

4 RECOMMENDATIONS

The following recommendations are based on this research:

1. Until the capital and operating cost estimates for the Lurgi and Koppers-Totzek gasification systems are confirmed by demonstration and actual use, conversion of boilers to coal at Army installations should use a direct combustion process.

2. Demonstrations of the Lurgi and Koppers-Totzek processes at nonindustrial Army installations should be actively pursued with ERDA.

3. At least four Army installations should be studied in detail to determine (1) how coal gasification can be applied to the total installation; (2) the costs of converting existing equipment and distribution systems; (3) coal supply, delivery, and storage considerations; and (4) necessary O&M procedures and staffing.